



Environmental radioactivity in Greenland in 1976

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Risø National Laboratory

Environmental Radioactivity in Greenland in 1976

by A. Aarkrog and J. Lippert

July 1977

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Environmental Radioactivity in Greenland in 1976

by

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Abstract

Measurements of fall-out radioactivity in Greenland in 1976 are reported. Strontium-90 (and Caesium-137 in most cases) was determined in samples of precipitation, sea water, vegetation, animals, and drinking water. Estimates are given of the mean contents of ^{90}Sr and ^{137}Cs in the human diet in Greenland in 1976.

Slougaard Jensen/København

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CONTENTS

	Page
1. Introduction	5
2. Results and Discussion	6
2.1. Strontium-90 in Precipitation	6
2.2. Strontium-90 in Sea Water	9
2.3. Strontium-90 and Caesium-137 in Terrestrial Animals	9
2.4. Strontium-90 and Caesium-137 in Sea Animals	10
2.5. Strontium-90 and Caesium-137 in Vegetation	11
2.6. Strontium-90 in Drinking Water	12
3. Estimate of the Mean Contents of ^{90}Sr and ^{137}Cs in the Human Diet in Greenland	14
4. Conclusion	19
Acknowledgements	20
References	20

ABBREVIATIONS AND UNITS

FP	fission products
pCi	picocurie, 10^{-12} Ci, $\mu\mu\text{Ci}$
nCi	nanocurie, 10^{-9} Ci, $m\mu\text{Ci}$
mCi	millicurie, 10^{-3} Ci
S.U.	pCi ^{90}Sr (g Ca) $^{-1}$
M.U.	pCi ^{137}Cs (g K) $^{-1}$
nSr	natural (stable) Sr
S.D.	standard deviation, $\sqrt{\frac{\sum (\bar{x}-x_i)^2}{(n-1)}}$
S.E.	standard error, $\sqrt{\frac{\sum (\bar{x}-x_i)^2}{n(n-1)}}$
S.S.D.	sum of squares of deviation, $\sum (\bar{x}-x_i)^2$
f	degrees of freedom
s ²	the variance
v ²	the ratio between the variance in question and the residual variance
P	the probability fractile of the distribution in question
\bar{x}	mean value
η	coefficient of variation, relative S.D.
Σ	sum
anova	analysis of variance
A	$\eta = 20-33\%$ (counting error)
B	$\eta > 33\%$ (counting error)
B.D.L.	below detection limit

gramme, a number of samples were obtained from the Royal Greenland Trade Company.

1.3.

The estimated mean diet in Greenland was the same as that in 1962, i.e., it agreed with the estimate given by Professor E. Hoff-Jørgensen, Ph.D.

1.4.

The environmental studies in Greenland were carried out together with corresponding investigations in Denmark (cf. Risø Report No. 361)²⁾ and in the Faroes (cf. Risø Report No. 362)³⁾.

1.5.

The present report does not repeat information concerning sample collection and analysis already given in ref. 1.

2. RESULTS AND DISCUSSION

2.1. Strontium-90 in Precipitation

Table 2.1.1 shows the results of the measurements.

The ⁹⁰Sr concentrations in 1976 at the Greenland stations were 0.3 times the 1975 figures. In Denmark²⁾ and the Faroes³⁾ the fall-out levels decreased similarly from 1975 to 1976. The low precipitation locations (Upernavik and Danmarkshavn) showed higher ⁹⁰Sr concentrations than the high precipitation sites (Prins Christians Sund) (cf. table 2.1.2).

Table 2.1.1

Strontium-90 in precipitation collected in Greenland in 1976

Location	Unit	Jan.-Mar.	Apr.-June	July-Sep.	Oct.-Dec.	1976
Upernavik	pCi l ⁻¹	0.47 A	0.46 A	1.25	0.12 B	\bar{x} 0.25
Σ 264 mm	mCi km ⁻²	0.007 A	0.014 A	0.034	0.011 B	Σ 0.066
Godhavn	pCi l ⁻¹	0.34 B	0.86 A	0.136	0.171	\bar{x} 0.193
Σ 466 mm	mCi km ⁻²	0.010 B	0.022 A	0.048	0.010	Σ 0.090
Godthåb	pCi l ⁻¹	0.30 B	0.20 A	0.144	0.18 A	\bar{x} 0.173
Σ 756 mm	mCi km ⁻²	0.023 B	0.023 A	0.063	0.022 A	Σ 0.131
Prins Chr.Sund	pCi l ⁻¹	0.161	0.135	0.045	0.078 A	\bar{x} 0.100
Σ 3032° mm	mCi km ⁻²	(0.086)	(0.109)	(0.052)	(0.075)	Σ 0.302
Kap Tobin	pCi l ⁻¹	0.146	(0.21)**	0.161	0.045 A	\bar{x} 0.110
Σ 736° mm	mCi km ⁻²	0.025	(0.023)	0.018	0.015 A	Σ 0.081
Danmarkshavn	pCi l ⁻¹	0.23 B	0.45 A	(0.14)**	(0.12)**	\bar{x} 0.25
Σ 158° mm	mCi km ⁻²	0.015 B	0.016 A	(0.004)	(0.004)	Σ 0.039
<p>* The missing amount of precipitation was kindly supplied by Mr. Gunnar Nielsen, Danish Meteorological Institute</p> <p>**Estimated from VAR 3</p>						

Table 2.1.2

Analysis of variance of ln pCi ⁹⁰Sr l⁻¹ precipitation in Greenland 1976
(from table 2.1.1)

Variation	SSD	f	s ²	v ²	P
Betw. quarters	3.586	3	1.195	6.375	> 99%
Betw. locations	1.906	5	0.781	4.166	> 97.5%
Remainder	2.250	12	0.188		

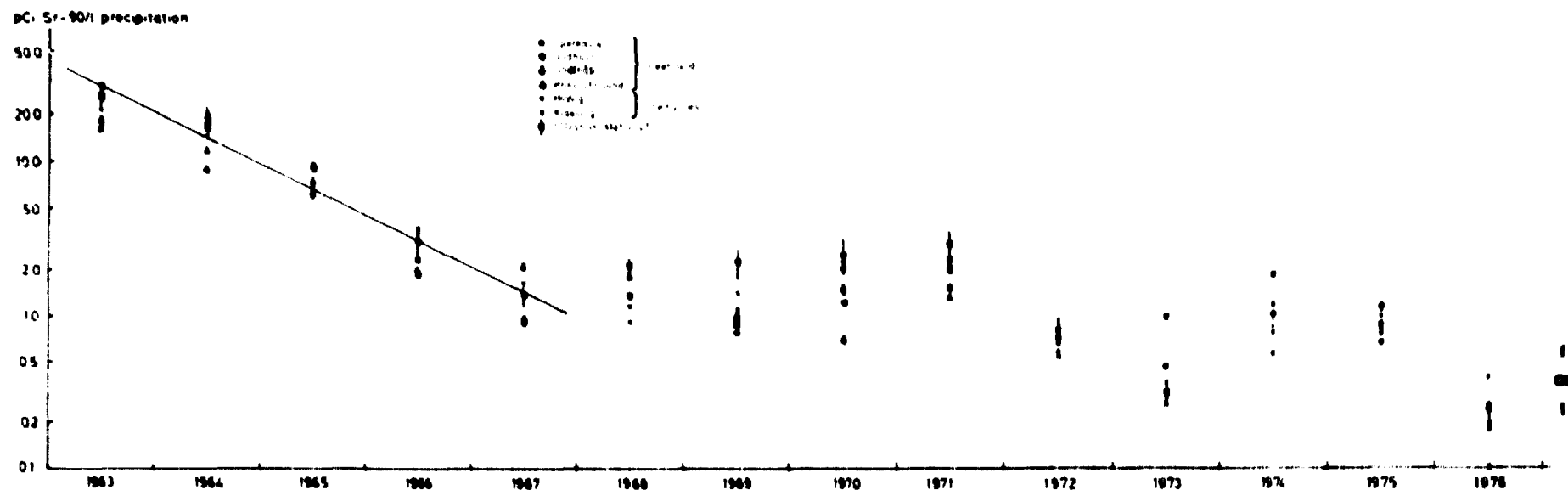


Fig. 2.1.2. Annual specific mean activity of ^{90}Sr in precipitation collected in Denmark, the Faroes, and Greenland in 1963-1976. The regression curve $y = 44.7 e^{-0.76t}$ was calculated from the ten Danish stations in 1963-1967, ($t = 0$, Jan. 1, 1963), $y = 4.3 e^{-1.08t}$ in 1971-1973 ($t = 0$, Jan. 1, 1971).

2.2. Strontium-90 in Sea-Water

One sample was obtained in 1976 from Prins Chr. Sund. It contained $0.15 \text{ pCi } ^{90}\text{Sr l}^{-1}$ and $1.11 \text{ pCi } ^{137}\text{Cs l}^{-1}$. The salinity was 18.9 o/oo. The ^{90}Sr level was comparable with those of the previous years. The $^{137}\text{Cs}/^{90}\text{Sr}$ mean ratio was as high as 7.4. We suspect the Greenland sea water to be contaminated with ^{137}Cs from Windscale^{2,3)}.

2.3. Strontium-90 and Caesium-137 in Terrestrial Animals

No reindeer samples were received in 1976.

Five samples of lamb were obtained through the Royal Greenland Trade Company and one sample directly from Julianehåb. The meat contained $4.9 \text{ pCi } ^{90}\text{Sr kg}^{-1}$ (49 S.U.) and $908 \text{ pCi } ^{137}\text{Cs kg}^{-1}$ ($268 \text{ pCi } ^{137}\text{Cs (g K)}^{-1}$). The bone contained $53 \text{ pCi } ^{90}\text{Sr (g Ca)}^{-1}$. The levels for lamb were generally higher than those in 1975. A sample of musk ox collected at Scoresbysund in November contained $48 \text{ pCi } ^{137}\text{Cs kg}^{-1}$ meat ($14.8 \text{ pCi } ^{137}\text{Cs (g K)}^{-1}$).

Table 2.3.2.1

Strontium-90 and Caesium-137 in lamb collected by the Royal Greenland Trade Company in 1976

Lamb	Sample type	$\text{pCi } ^{90}\text{Sr kg}^{-1}$	$\text{pCi } ^{90}\text{Sr (g Ca)}^{-1}$	$\text{pCi } ^{137}\text{Cs kg}^{-1}$	$\text{pCi } ^{137}\text{Cs (g K)}^{-1}$
I	Meat	3.1	41	1240	330
I	Bone	-	43	-	-
II	Meat	5.0	49	1710	480
II	Bone	-	57	-	-
III	Meat	5.3	52	370	104
III	Bone	-	53	-	-
IV	Meat	3.6	41	770	193
IV	Bone	-	48	-	-
V	Meat	4.1	38	810	220
V	Bone	-	39	-	-
Julianehåb	Meat	8.1	75	550	279
	Bone	-	79	-	-

Table 2.3.2.2

Strontium-90 and Caesium-137 in Guillemot collected in Greenland (Julianehåb) in 1976

Sample type	pCi ^{90}Sr (g Ca) $^{-1}$	pCi ^{137}Cs kg $^{-1}$	pCi ^{137}Cs (g K) $^{-1}$
Meat	-	18.4 A	6.5 A
Bone	0.043 A	-	-
Pluck	-	B.D.L	B.D.L

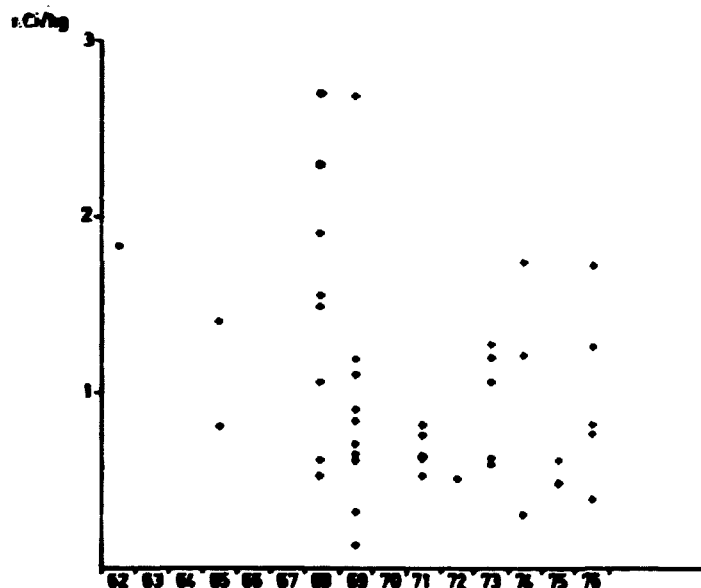


Fig. 2.3.1. Caesium-137 in mutton 1962-76.

2.4. Strontium-90 and Caesium-137 in Sea Animals

The levels in fish, shrimps and seals are shown in table 2.4.1. The mean levels in fish and shrimps were: 0.4 pCi ^{90}Sr kg $^{-1}$ meat, 14 pCi ^{137}Cs kg $^{-1}$ meat, and seal contained 0.1 pCi ^{90}Sr kg $^{-1}$ meat and 27 pCi ^{137}Cs kg $^{-1}$.

Table 2.4.1

Strontium-90 and Caesium-137 in sea animals collected in Greenland in 1976

Location	Species	Sample type	pCi ⁹⁰ Sr kg ⁻¹	pCi ⁹⁰ Sr (g Ca) ⁻¹	pCi ¹³⁷ Cs kg ⁻¹	pCi ¹³⁷ Cs (g K) ⁻¹
Julianehåb	Greenland halibut	Meat	0.24	0.26	20 A	6.4 A
	" "	Bone	-	0.19 B	-	-
	Cod fillet	Meat	0.21 B	-	11.6	5.4
	Cod	Meat	0.27 B	0.53 B	20.0	7.2
	"	Bone	-	0.17	-	-
K.G.H.*	Cod	Meat	0.16 B	1.6 B	22	7.5
K.G.H.*	Salmon I	Meat	0.86 A	2.0 A	8.5 A	2.2 A
	" "	Bone	-	0.41	-	-
	Salmon II	Meat	0.12 B	0.35 B	11.0	3.4
	" "	Bone	-	0.21 A	-	-
K.C.H.*	Shrimp I	Meat	0.81	1.34	7.9 A	5.9 A
	" II	Meat	0.70 B	1.09 B	8.2 A	7.1 A
K.G.H.*	Seal I	Meat	B.D.L	B.D.L	36	11.8
	Seal II	Meat	B.D.L	B.D.L	22	7.1
	" "	Bone	-	0.06 B	-	-
	Seal III	Meat	0.07 B	1.1 B	33	11.0
	" "	Bone	-	0.06 A	-	-
Julianehåb	Seal	Meat	0.09 B	1.6 B	33	11.9
Scoresby-sund	Seal *	Meat	0.15 B	1.9 B	22	8.2
	" "	Bone	-	0.082A	-	-
	Seal II	Meat	0.19 B	1.7 B	15.4	6.0
	" "	Bone	-	0.077	-	-
*Royal Greenland Trade Company						

2.5. Strontium-90 and Caesium-137 in Vegetation

Lichen, moss, grass, and seaweed were collected along the Greenland coast during the summer. Table 2.5 shows the results.

The geometric mean levels in moss and lichen were 5.7 nCi ⁹⁰Sr kg⁻¹ and 21 nCi ¹³⁷Cs kg⁻¹. These levels are in good agreement with the values observed earlier (cf. fig. 2.5).

Table 2.5

Strontium-90 and Caesium-137 in vegetation samples collected in Greenland in 1976

Location	Species	pCi ^{90}Sr kg $^{-1}$	pCi ^{90}Sr (g Ca) $^{-1}$	pCi ^{137}Cs kg $^{-1}$	pCi ^{137}Cs (g K) $^{-1}$
Sukkertoppen	Lichen	5,000	-	16,000	-
Scoresbysund	Lichen	18,300	3,400	24,000	13,900
Sukkertoppen	Moss	6,000	2,400	9,500	3,600
Prins Chr.sund	Moss	1,900	1,540	52,000	5,400
Prins Chr.sund	Crowberry leaves and twigs	2,500	990	8,300	2,500
Scoresbysund	Grass	370	125	640	34
Prins Chr.sund	Seaweed	31	2.7	23 B	0.9 B

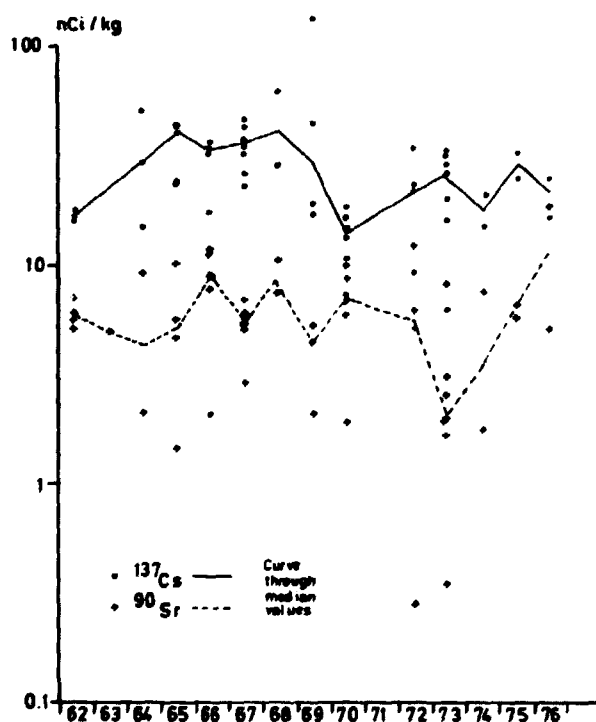


Fig. 2.5. Caesium-137 and Strontium-90 in lichen (fresh weight) collected along the Greenland coast 1962-76.

2.6. Strontium-90 in Drinking Water

Quarterly samples of drinking water were collected from a number of locations in Greenland. Table 2.6 shows the results from 1976, and fig. 2.6 the results from four of the locations for the period 1962-1976.

Table 2.6

Strontium-90 in drinking water collected in Greenland in 1976
(pCi ^{90}Sr l $^{-1}$)

Location	Jan.-March	April-June	July-Sep.	Oct.-Dec.
Danmarkshavn	1.72	2.26	1.35	
Upernavik	0.036 B	0.30 A	0.51	0.03 B
Godthåb	0.33	0.42	0.43	0.31
Prins Chr.sund	3.5	0.68	0.36	2.4
Godhavn	0.06 B	0.099	0.099	
Scoresbysund		0.43	0.176	

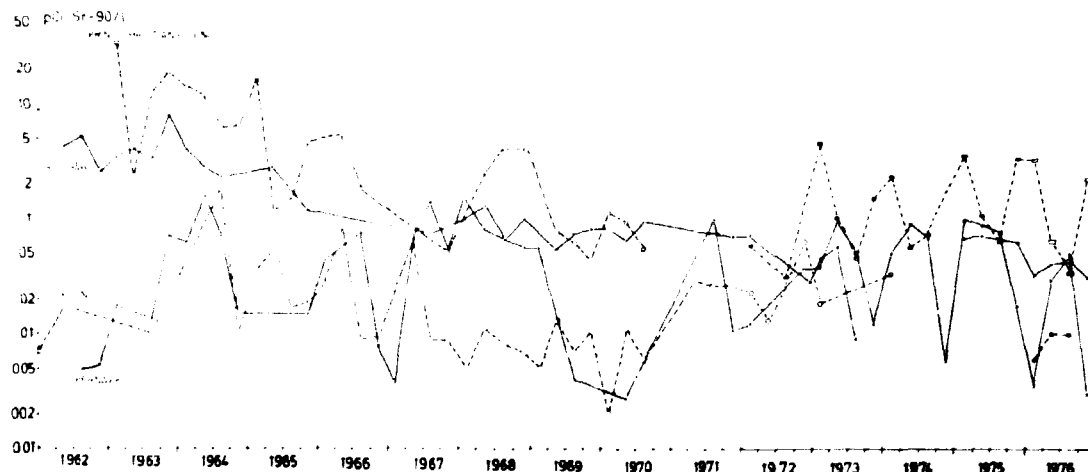


Fig. 2.6. Strontium-90 in Greenland drinking water, 1962-76.

As in previous years, we found it most expedient to choose the geometric mean of all figures, i.e. 0.36 pCi ^{90}Sr l $^{-1}$, as representative of the mean level of ^{90}Sr in Greenland drinking water in 1976.

Fig. 2.6 shows that the difference between the various locations has been less pronounced in recent years.

3. ESTIMATE OF THE MEAN CONTENTS OF ^{90}Sr AND ^{137}Cs IN THE HUMAN DIET IN GREENLAND IN 1976

3.1. The Annual Quantities

The estimate of the daily per capita intake of the different foods in Greenland is still based on the figures given in 1962 by Professor E. Hoff-Jørgensen, Ph.D., in Risø Report No. 65¹⁾.

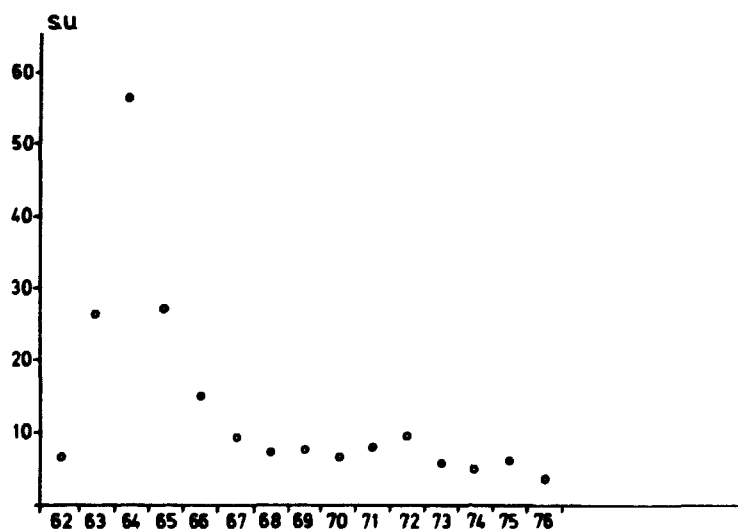


Fig. 3.1. Strontium-90 in Greenland diet, 1962-76.

3.2. Milk Products

All milk consumed in Greenland was imported as milk powder from Denmark. The mean radioactivity content in milk prepared from Danish dried milk produced in 1976 was 4.1 pCi ^{90}Sr kg⁻¹ and 4.3 pCi ^{137}Cs kg⁻¹ 2).

Cheese was also imported from Denmark and contained 28.9 pCi ^{90}Sr kg⁻¹ and 3.1 pCi ^{137}Cs kg⁻¹.

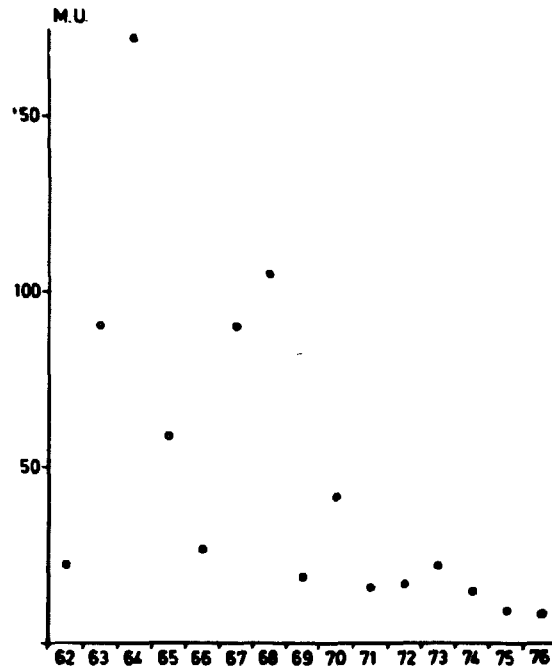


Fig. 3.2. Caesium-137 in Greenland diet, 1962-76.

3.3. Grain Products

All grain was imported from Denmark. It is assumed that only grain from the harvest of 1975 was consumed in Greenland during 1975. The daily per capita consumption was: rye flour (100% extraction): 80 g, wheat flour (75% extraction): 110 g, rye flour (70% extraction): 20 g, biscuits (rye, 100% extraction): 27 g, and grits: 25 g. The content of ^{90}Sr in these five products was 20, 4, 4, 15, and 12 pCi kg^{-1} respectively. Hence the mean content of ^{90}Sr in grain products was 11 pCi kg^{-1} . The content of ^{137}Cs in the five products was 17, 5, 8, 13, and 12 pCi kg^{-1} . Hence the mean content of ^{137}Cs in grain products was 10 pCi kg^{-1} .

The activity levels in rye flour (100% extraction), wheat flour (75% extraction), and grits were all taken from tables 5.9.1 and 5.9.2 in Risø Report No. 361²⁾. The ^{90}Sr level in rye flour (70% extraction) was calculated analogously with the level in wheat flour (75% extraction), i.e. as one-fifth of the whole-grain activity. The ^{137}Cs content in rye flour (70% extraction) was calculated as one half of the whole-grain level in rye in analogy with the ratio between ^{137}Cs in whole wheat grain and in wheat flour (75% extraction)²⁾. The ^{90}Sr and ^{137}Cs contents

in biscuits were calculated by dividing the levels of the rye flour (100% extraction) by 1.35, since 1 kg flour yields 1.35 kg bread²⁾.

3.4. Potatoes, Other Vegetables, and Fruit

The Danish mean levels for 1976 were used²⁾ since the local production is insignificant compared with imports from Denmark.

The Danish mean levels were: in potatoes $1.7 \text{ pCi } ^{90}\text{Sr kg}^{-1}$ and $2.2 \text{ pCi } ^{137}\text{Cs kg}^{-1}$, in other vegetables $6.6 \text{ pCi } ^{90}\text{Sr kg}^{-1}$ and $2.8 \text{ pCi } ^{137}\text{Cs kg}^{-1}$, and in fruit $2.3 \text{ pCi } ^{90}\text{Sr kg}^{-1}$ and $2.0 \text{ pCi } ^{137}\text{Cs kg}^{-1}$.

3.5. Meat

Nearly all meat consumed in Greenland is assumed to be of local origin. Approx. 10% comes from sheep, 5% from reindeer, 60% from seals, 5% from whales, and 20% from sea birds and eggs.

The activity in reindeer was estimated from the 1975 levels¹⁾ and lamb was estimated from 2.3. Activity in seals and whales was estimated from table 2.4.1 (whales were assumed equal to seals), while sea birds and eggs were estimated from table 2.3.2.2 to contain $0 \text{ pCi } ^{90}\text{Sr kg}^{-1}$ and $18 \text{ pCi } ^{137}\text{Cs kg}^{-1}$. Hence the mean levels in Greenland meat from 1976 were $0.8 \text{ pCi } ^{90}\text{Sr kg}^{-1}$ and $141 \text{ pCi } ^{137}\text{Cs kg}^{-1}$.

3.6. Fish

All fish consumed was of local origin, and the mean levels from 2.4 were used, i.e. $0.4 \text{ pCi } ^{90}\text{Sr kg}^{-1}$ and $14 \text{ pCi } ^{137}\text{Cs kg}^{-1}$.

3.7. Coffee and Tea

The Danish figures for 1976²⁾ were used for coffee and tea, i.e. $7.3 \text{ pCi } ^{90}\text{Sr kg}^{-1}$ and $35.7 \text{ pCi } ^{137}\text{Cs kg}^{-1}$.

3.8. Drinking Water

The geometric mean calculated in 2.6 was used as the mean level of ^{90}Sr in drinking water, i.e. $0.36 \text{ pCi } ^{90}\text{Sr l}^{-1}$. The ^{137}Cs content was as previously¹⁾ estimated at 1/4 of the ^{90}Sr content, i.e. approx. $0.1 \text{ pCi } ^{137}\text{Cs l}^{-1}$.

Tables 3.1 and 3.2 show the diet estimates of ^{90}Sr and ^{137}Cs respectively.

Table 3.1

Estimate of the mean content of ^{90}Sr in the human diet
in Greenland in 1976

Type of food	Annual quantity in kg	pCi ^{90}Sr per kg	Total pCi ^{90}Sr	Percentage of total ^{90}Sr in food
Milk and cream	78	4.1	320	16.8
Cheese	2.5	28.9	72	3.8
Grain products	95.6	11	1052	55.2
Potatoes	32.8	1.7	56	2.9
Vegetables	5.5	6.6	36	1.9
Fruit	13.5	2.3	31	1.6
Meat and eggs	45.6	0.8	36	1.9
Fish	127.6	0.4	51	2.7
Coffee and tea	7.3	7.3	53	2.8
Drinking water	548	0.36	197	10.4
Total			1904	100.0
The mean annual calcium intake is estimated to be 560 g (approx. 200-250 g creta praeparata). Hence the ^{90}Sr (g Ca) $^{-1}$ ratio in Greenland total diet in 1976 was 3.4 S.U. and the daily intake 5.2 pCi ^{90}Sr .				

Table 3.2

Estimate of the mean content of ^{137}Cs in the human diet
in Greenland in 1976

Type of food	Annual quantity in kg	pCi ^{137}Cs per kg	Total pCi ^{137}Cs	Percentage of total ^{137}Cs in food
Milk and cream	78	4.3	335	3.4
Cheese	2.5	3.1	8	0.1
Grain products	95.6	10	956	9.6
Potatoes	32.8	2.2	72	0.7
Vegetables	5.5	2.8	15	0.1
Fruit	13.5	2.0	27	0.3
Meat and eggs	45.6	141	6430	64.7
Fish	127.6	14	1786	18.0
Coffee and tea	7.3	35.7	261	2.6
Drinking water	648	0.1	55	0.5
Total			9945	100.0
The mean annual potassium intake is estimated to be approx. 1200 g. Hence the ^{137}Cs (g K) $^{-1}$ ratio becomes 8.3 pCi ^{137}Cs (g K) $^{-1}$. The daily intake in 1976 from food was 27 pCi ^{137}Cs .				

3.9. Discussion

The most important ^{90}Sr source in the Greenland diet is still grain products, which contribute 55.2% of the total ^{90}Sr content in the diet. Drinking water came next in importance, contributing 10.4%. Approx. 85% of the ^{90}Sr in the food consumed in Greenland in 1976 originated from imported Danish food.

Meat is still the most important ^{137}Cs source in the Greenland diet, contributing 64.7% of the total content in 1976. Approx. 83% of the ^{137}Cs in the Greenland diet in 1976 came from local products.

As compared with the 1975 figures, the ^{90}Sr content in the total diet in 1976 was approx. half the 1975 level, while the ^{137}Cs level was nearly equal to the 1975 level.

To estimate the maximum per capita intakes of ^{90}Sr and ^{137}Cs in Greenland in 1976 we again assume¹⁾ that the only grain product consumed by a person is dark rye bread, and that he only eats lamb meat. His daily intake of ^{90}Sr is thus 8 pCi (5.3 S.U.) and his ^{137}Cs intake 125 pCi day⁻¹ (using the quantities in tables 3.1 and 3.2). At the lower limit we can imagine a person eating white bread and fish (instead of meat) and drinking water with hardly any activity (e.g. water formed by the melting of old ice). In this case the daily intakes are 2.8 pCi ^{90}Sr (1.8 S.U.) and 9.8 pCi ^{137}Cs . Hence the ratios between the levels in the maximum and minimum diets become 2.9 for ^{90}Sr and 12.8 for ^{137}Cs .

The ^{90}Sr content of the Greenland diet was 79% of the estimated Danish mean content²⁾, and 42% of the Faroese level³⁾. The ^{137}Cs level in the total diet in Greenland was 2.4 times that of the Danish diet and five times lower than the Faroese diet level.

4. CONCLUSION

4.1.

The ^{90}Sr fall-out rates in 1976 were the following: Godhavn: approx. $0.1 \text{ mCi } ^{90}\text{Sr km}^{-2}$; Godthåb: $0.2 \text{ mCi } ^{90}\text{Sr km}^{-2}$; Prins Christians Sund: approx. $0.3 \text{ mCi } ^{90}\text{Sr km}^{-2}$; Upernavik: $0.07 \text{ mCi } ^{90}\text{Sr km}^{-2}$. The accumulated fall-out levels by the end of 1976 were estimated at approx. $25 \text{ mCi } ^{90}\text{Sr km}^{-2}$ at Godhavn, $37 \text{ mCi } ^{90}\text{Sr km}^{-2}$ at Godthåb, $136 \text{ mCi } ^{90}\text{Sr km}^{-2}$ at Prins Christians Sund, and $14 \text{ mCi } ^{90}\text{Sr km}^{-2}$ at Upernavik.

4.2.

The food consumed in Greenland in 1976 contained on the average $3.4 \text{ pCi } ^{90}\text{Sr (g Ca)}^{-1}$, and the daily mean intake of ^{137}Cs was estimated at 27 pCi. The most important ^{90}Sr contributors to the diet were grain products and milk products, together accounting for approx. 76% of the total ^{90}Sr content of the diet. Caesium-137 originated mainly from meat (reindeer and lamb) and fish, contributing 83% of the total ^{137}Cs content of the diet.

4.3.

No ^{90}Sr analyses of human bone samples have hitherto been carried out on the population of Greenland. Considering the estimated ^{90}Sr levels in the diet, it seems probable⁴⁾, however, that the 1976 ^{90}Sr levels of humans in Greenland were on the average rather similar to those found in Denmark, i.e. the mean levels in human bone in Greenland were approx. 1 S.U. (vertebrae).

From diet measurements the ^{137}Cs content in Greenlanders was estimated at $20 \text{ pCi } ^{137}\text{Cs (g K)}^{-1}$.

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